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E. E. Bachtell, S. S. Bettadapur, J. V. Coyner, and C. E. Farrell

Martin Marietta Denver Aerospace
Denver, CO 80201

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16. Abstract

Designs are synthesized for direct sound broadcast satellite systems for HF-, VHF-, L-, and Ku-bands. Methods are developed and used to predict satellite weight, volume, and RF performance for the various concepts considered. Cost and schedule risk assessments are performed to predict time and cost required to implement selected concepts. Technology assessments and tradeoffs are made to identify critical enabling technologies that require development to bring technical risk to acceptable levels for full scale development.

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FOREWORD

This report was prepared by Martin Marietta Denver Aerospace under Contract NAS3-24233. The contract was administered by the Lewis Research Center (LeRC) of the National Aeronautics and Space Administration (NASA). The study was performed from April 1984 to June 1985 and the NASA-LeRC project manager was Mr. Grady Stevens.

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SATELLITE VOICE BROADCAST SYSTEM STUDY

Eric E. Bachtell, Shailesh S. Bettadapur, John V. Coyner, and

Curtis E. Farrell

Martin Marietta Denver Aerospace

SUMMARY

The primary goal of this study was to develop technical, schedule, and cost data that can be used by the U.S. Information Agency to evaluate use of sound broadcast satellite systems to meet future international sound broadcast needs. Satellite systems launchable by the space shuttle were synthesized and analyzed for broadcast at four frequencies: 26 MHz (HF-band); 47 MHz (VHF-band); 1.5 GHz (L-band); and 12.2 GHz (Ku-band). Broadcast requirements for the study specified time of day, duration of broadcast, and ranges of ground signal strength. Results showed that satellite systems can meet Ku-band requirements. L-band systems were designed that can meet lower signal strength requirements. Neither VHFnor HF-band requirements can be met by realistic satellite systems. For these latter bands, the study results identified the maximum possible broadcast capabilities for each concept. Also, for HF-band systems, parametric relationships were derived to identify available signal strength and satellite mass vs satellite output power. Time and cost to implement each system were estimated, and risk assessments performed to identify 90 and 10% risk values of time and cost.

INTRODUCTION

The Satellite Voice Broadcast System Study was commissioned by NASA to investigate the feasibility of a Direct Voice Broadcast System (DVBS) in space. The study evaluated potential operating systems in four frequency bands: 26 MHz, 47 MHz, 1.5 GHz, and 12.2 GHz. Potential operational system concepts were defined to a depth sufficient to determine the relative technical characteristics, performance, and costs (development, construction, and operating), and to develop schedules of selected system concepts. In addition, an assessment of the impact of and need for advanced technology for these system concepts was performed.

BACKGROUND

The use of satellites to provide sound broadcasting was examined by NASA as early as 1967 (ref. 1 and 2). More recently, this service has received increasing attention for both national and international broadcasting interests. CCIR Report 955 (ref. 3) deals with the feasibility of sound broadcasting satellite systems operating in the range of 500 MHz to 2 GHz. The primary application in Report 955 is broadcasting to automotive or portable receivers having relatively low gain antennas; in this case rather large satellites are required due to large multipath fade margins.

An extension of this work by Chaplin, et al. considered only the rural broadcasting case and an improved receiver noise performance. Their analyses for this special case (ref. 4) indicates that national broadcasting at 1 GHz is feasible with rather conventional size spacecraft. Phillips and Knight (ref. 5) explored the same subject at 26 MHz. None of these studies considered the operational difficulties of worldwide sound broadcasting but confined themselves to restricted coverage, single satellite concepts.

The U.S. Information Agency (USIA)/Voice of America (VOA) is considering sound broadcasting by satellite as part of a program to renovate, modernize, and expand the existing worldwide USIA/VOA broadcasting network. With such comprehensive coverage, new difficulties are introduced to satellite broadcasting. Therefore, it is appropriate to examine worldwide conceptual and operational satellite sound broadcast systems to delineate these difficulties and to continue to examine the practicality of worldwide sound broadcasting by satellite. This will clarify the more subtle operational difficulties of satellite sound broadcasting and provide guidance to the more favorable broadcast bands and technologies to use.

PROGRAM OBJECTIVE

The objective of this study was to provide the data necessary to develop technical, schedule, and cost data to aid in evaluating alternatives for satisfying future international sound broadcasting needs of the U.S. Government.

Conventional terrestrial broadcasting techniques were excluded from this study. Satellite system concepts were synthesized and optimized for operation in each of four bands: 15.1-26.1 MHz, 47-68 MHz, 1.5 GHz, and 11.7-12.5 GHz. The technical and operating characteristics of the space segment were studied in sufficient detail to demonstrate technologically feasible and cost-effective launch, deployment, and operational capabilities; critical technologies were identified; project plans were prepared defining tasks and providing estimates of schedules and costs to construct and operate such systems. Project plans were separately addressed for the technical, schedule, and cost elements of development efforts required in each of the critical technology areas. Alternative approaches were developed that reduce risk and schedule associated with the development of these critical technologies. Systems costs (development, construction, implementation, and operation) and their associated funding profiles were delineated in sufficient detail to separately facilitate life-cycle and cost-effectiveness comparisons.

Also, the technical and operating characteristics of the telemetry, tracking, and control station and the associated feeder link were defined in sufficient detail to develop estimates of technical, schedule, and cost data for this segment. Global service coverage combined with centralized system control and program feed from the U.S. or its territories is a desirable system feature.

Program outputs are summarized in Table 1.

TABLE 1. - PROGRAM OUTPUTS

– For several sets of operating requirements, what are the most cost-effective satellite system concepts?
– What is the impact on selected systems concepts of variations in the operating requirements?
– What critical technology must be developed for the various sound DBS system options? What are the estimated development costs & schedule?
– What are the cost & schedule risks in developing the sound DBS system options?
– What is the least costly implementation approach to each of the sound DBS system options?

PROGRAM REQUIREMENTS

The VOA requirements include specification of zones to be covered, universal time coordinated (UTC) times and number of channels, frequency of operation, and power flux density (PFD). A variety of options were also studied to provide a broad data base to not only study system designs but also to provide insight into optional system requirements.

Figure 1 pictorially describes the 15 zones of interest. The broadcast requirements for the zones are presented in Figure 2. Times are presented in 15-minute increments (UTC times) for a 24-h day. For Ku-band, L-band, and HF-band, all zones were to be covered. As a baseline for VHF-band, only Zones 9, 10, 12, and 14 were to be covered.

Figure 1 (32 lines)

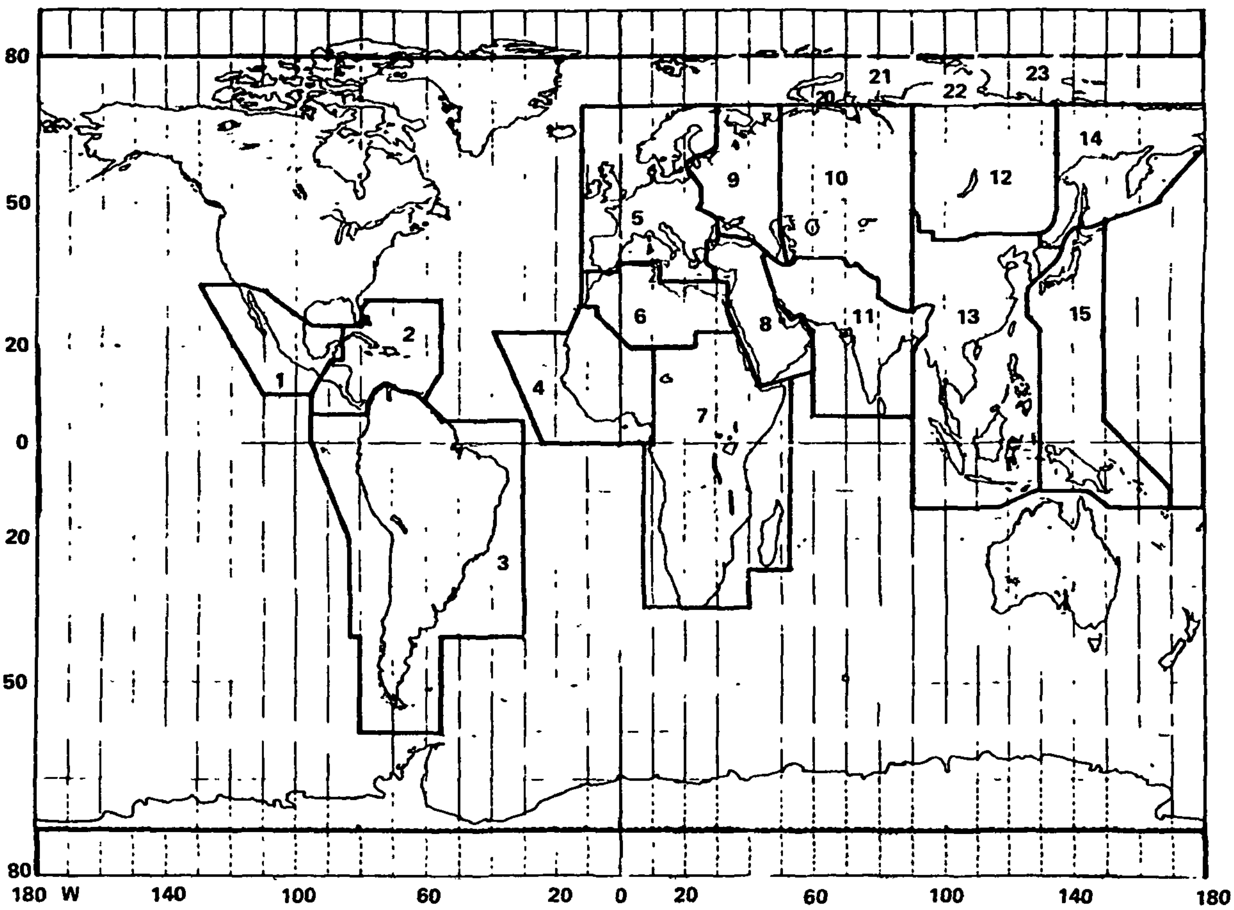

Figure 1. - VOA coverage zones.

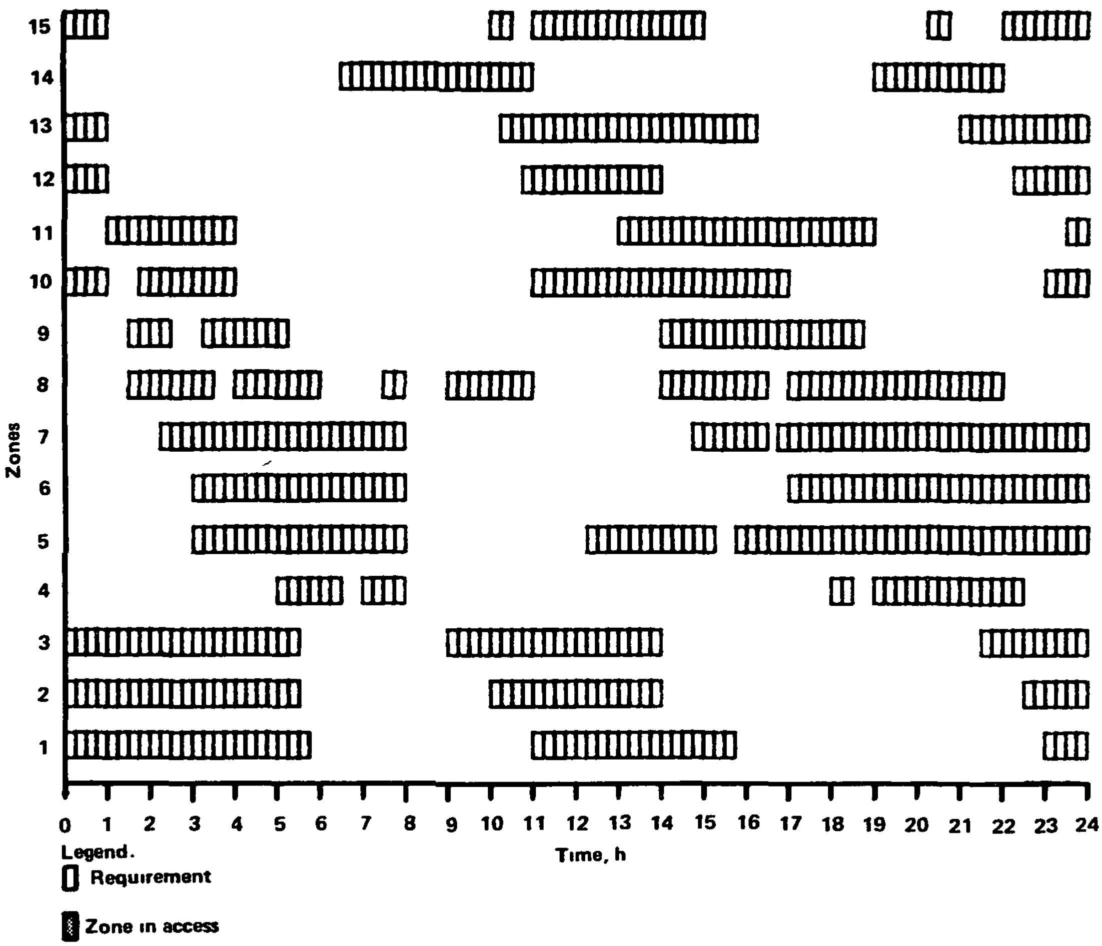

Figure 2 - VOA 24-hour broadcast requirements.

Table 2 presents the program requirements for Ku-band including frequency of operation, zones, maximum simultaneous channels and signal strength. No options were evaluated for the Ku-band system.

Table 3 presents the program requirements for L-band. Three signal levels were initially specified, however, due to high power requirements on the satellite for power levels P_1 and P_3, emphasis was placed on the P_2 level with a high and low power requirement.

TABLE 2. - PROGRAM REQUIREMENTS—KU-BAND: 11.7 GHZ

Zone	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
No. of channels	2	2	2	2	11	3	4	2	6	3	4	2	6	2	1
— Signal level. -128 dBW/m^2/4 kHz (maximum)															

TABLE 3. - PROGRAM REQUIREMENTS L-BAND: 1.5 GHZ ± 25 MHZ

Zone	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
No. of channels	2	2	2	2	11	3	4	2	6	3	4	2	6	2	1

— Signal level: P_1, P_2*, P_3

P_1 — (-91.2) *Power flux density required to achieve an acceptable signal in a portable receiver or a receiver in an automobile.* Obtain this value as follows:

P_1 = 107 + 20 LOG f + M

where M = 12.5 + 0.17f -0.17ϕ + 1.65 [6.4 - 1.19f - 0.05ϕ]

f = Frequency in GHz

ϕ = Elevation angle of satellite in degrees

P_2 — (-103.6) Power flux density sufficient to achieve 49 dB demodulated S/N ratio with a receiver inside a single family dwelling making *use of an outside antenna.*

P_3 — (-92.6) Power flux density sufficient to achieve 49 dB demodulated S/N ratio with a receiver & antenna inside a single family dwelling having an 11 dB wall attenuation.

*P_2 selected for satellite parametrics at two power levels (-103.6 dBW/m^2 & a less conservative -116.1 dBW/m^2) P_1 & P_3 power levels not achievable

Table 4 presents the program requirements for VHF-band. Only Zones 9, 10, 12, and 14 were specified for coverage. Three power levels were initially specified (250, 1000, and 5000 V/m). The 1000 and 5000 V/m signal levels were not achievable so program emphasis was placed on 250 V/m with a 150 V/m option and reduced channel options. A single orbiter was specified as the baseline but an option using a satellite in one orbiter and a large Centaur-type stage in a second orbiter was also considered.

TABLE 4. - PROGRAM REQUIREMENTS — VHF-BAND: 47 - 68 MHZ

Zone	9	10	12	14
No. of channels	6	3	2	2

— Signal level: 250, 1000*, 5000* μV/m FM

— Optional systems studied
  — Reduced channel requirements (selective reduction)
  — Reduced signal level: 150 μV/m
  — Satellite using full orbiter

*1000 & 5000 μV/m were not achieveable (150 & 250 μV/m were *emphasized in program)*

Table 5 presents the program requirements for HF-band. Three power levels were initially specified: 300, 500, and, 1000 V/m. The 500 and 1000 V/m signal levels were not achievable so program emphasis was placed on 200 V/m with a 150 V/m option. Reduced channel requirements and two reduced zone coverages were also to be evaluated. Single spacecraft in six different orbits were also evaluated at three signal levels for both double sideband (DSB) and single sideband (SSB). A full orbiter spacecraft was also investigated to provide greater capability on a single satellite.

TABLE 5. - PROGRAM REQUIREMENTS HF-BAND: 15.1 - 26.1 MHZ

Zone	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
No. of channels	2	2	2	2	11	3	4	2	6	3	4	2	6	2	1

— *Signal levels: 300, 500*, & 1000* μV/m double sideband (DSB)*

— Optional systems studied
  — *Reduced channel requirements (six-channel max, one-channel max, selective reduction)*
  — Reduced signal level: 150 μV/m
  — *Small single spacecraft (DSB & single sideband [SSB]), 50, 150, 300 μV/m*
  — Reduce coverage to 40° N. & 15° S. Lat. lat.
  — Reduce coverage to 40-70° N. & 15-60° S. lat.
  — Satellite using full orbiter

*500 & 1000 μV/m were not achievable (150 & 300 μV/m were emphasized in program)

Nonorbital, nonterrestrial broadcast techniques are unable to meet the desired coverage even using large numbers of platforms. Both the numbers and resulting cost of the systems are excessive. Also, the nonorbital techniques evaluated are severely power limited and therefore, cannot penetrate into unfriendly territory as well as terrestrial systems.

Orbital techniques using derivatives of existing geostationary satellites can meet Ku-band requirements. L-band systems could be used at the lower power flux density (PFD) requirements of $-116.1\ dBW/m^2$. VHF and HF do not exist either with aperture or power subsystems to meet even the minimum signal strength requirement. Table 6 summarizes the results of existing nonterrestrial broadcast techniques.

The results of the Ku-band system design are summarized in Table 7. All VOA requirements could be achieved using existing technology and low program cost. Three satellites are required resulting in a total life-cycle cost of $1240M for a 20-yr operational lifetime with a corresponding cost per channel hour of $568. Figure 3 shows the proposed Ku-band satellite.

TABLE 6. - SUMMARY OF PROGRAM RESULTS FOR NONTERRESTRIAL BROADCAST TECHNIQUES

Summary of results
Nonorbital techniques
– Not useful in unfriendly territory.
– Many (19 to 719) platforms needed for a single zone.
Orbital techniques
– Practical systems operate only at geostationary orbit.
– Beam size in HF- & VHF-bands larger than Earth, and power is prohibitive.
– L-band system could work with existing broadcast technique for minimum PFD requirement only.
– Ku-band systems may work with existing SBS type satellite technology.

TABLE 7. - SUMMARY OF PROGRAM RESULTS FOR KU-BAND SYSTEM

3 Ku-band satellites in geostationary orbit meet program requirements.
– Uses existing technology
– LCC = $1,240M
– Cost/channel hour = $568/channel hour
– TOS/AMS launch vehicle
– 100% coverage

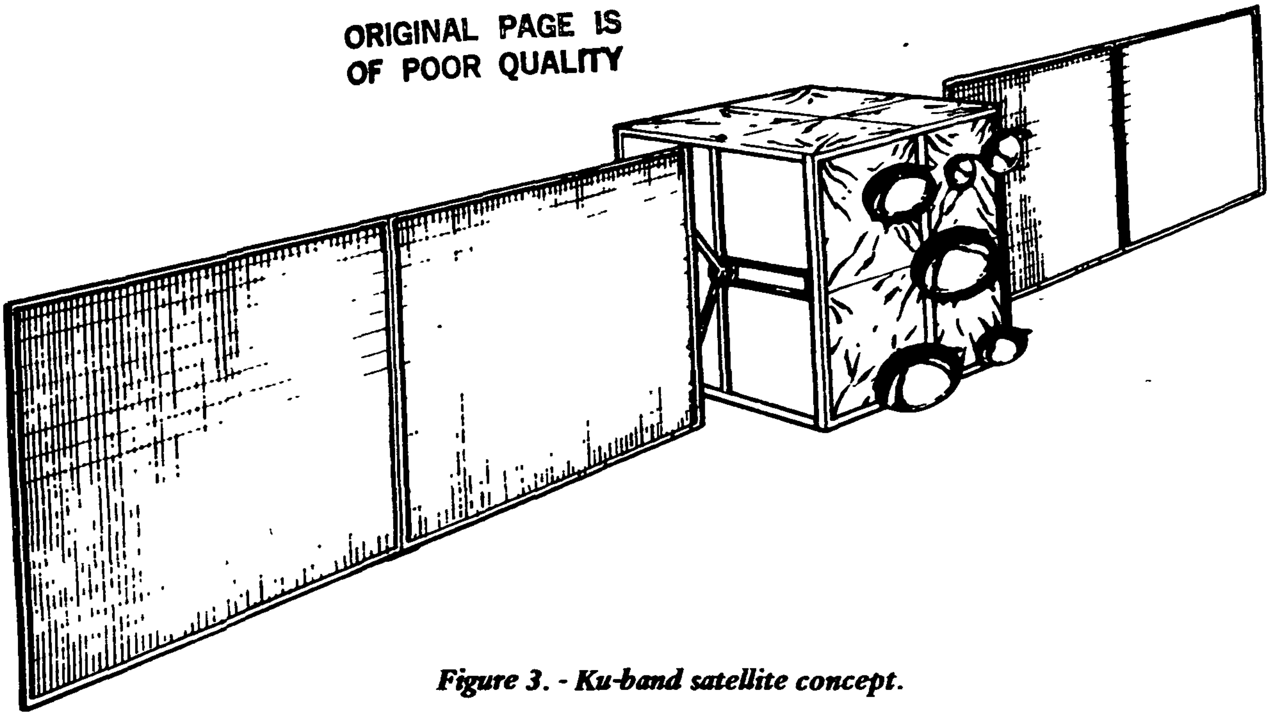

Figure 3. - Ku-band satellite concept.

The results of the L-band system design are summarized in Table 8. This design option uses the lower power requirement of -116.1 dBW/m^2. Each of three satellites has two antenna array apertures that cover multiple zones with one large spot. All VOA requirements could be achieved using existing technology and low program cost. The 17-kW power subsystem would require the use of SAFE array technology that was demonstrated by NASA. The three satellites have a 20-yr operational lifetime cost of $1353M and a cost per channel hour of $619. Two other low-power options and one high-power option were also studied. Figure 4 shows the proposed L-band satellite.

TABLE 8. - SUMMARY OF PROGRAM RESULTS FOR L-BAND SYSTEM

3 L-band satellites in geostationary orbit meet program requirements.
– Uses existing technology for -116.1 dBW/m^2
– LCC = $1,353M
– Cost/channel hour--$619/channel hour
– Requires 17 kW on satellite
– Two array antennas per satellite
– TOS/AMS launch vehicle
– 100% coverage

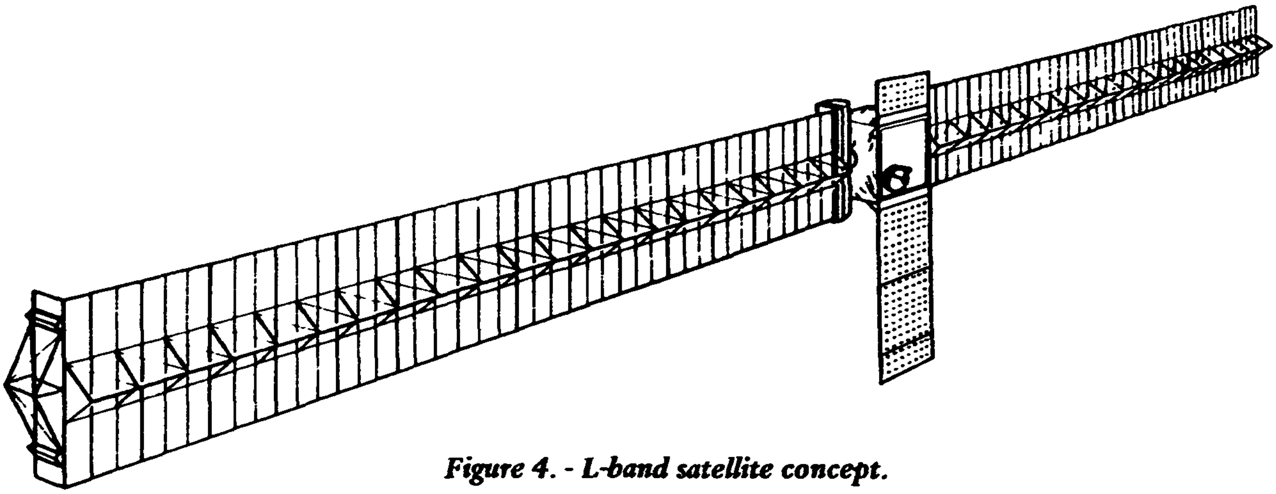

Figure 4. - L-band satellite concept.

The results of the VHF-band system design are summarized in Table 9. A four satellite constellation in a 24-hour elliptical orbit provides 140-150 V/m performance at the minimum cost. The 12-hour orbit had a higher PFD (250 V/m) but required eight satellites and had lower coverage efficiency. A deployable scanning array is used for the aperture and a deployable 31.3 kW solar array flight experiment (SAFE) type solar array was used. The four satellites have a 20-yr operational lifetime cost of $2945M with cost per channel hour of $8584. Figure 5 shows a proposed VHF-band satellite.

TABLE 9. - SUMMARY OF PROGRAM RESULTS FOR VHF SYSTEM

Four VHF-band satellites in a 24-h elliptical orbit can meet 140-150 μV/m requirement. – New technology for 168 m array & transmitters – 31.3 kW satellite power existing technology (SAFE) – LCC = $2945 – Cost/channel hour–$8584/channel hour – Centaur G launch vehicle – 100% coverage

The results of the HF-band system showed that excessively large numbers of satellites are required (88) to meet all zone and channel requirements at 300 V/m. By reducing requirements to 150 V/m a constellation of eight satellites can provide the number of channels shown in Table 10. New technology is required for both the array antenna and the power subsystem. It is anticipated that space station will develop the technology for a 100 kW solar power system. The eight satellites have a 20-yr operational lifetime cost of $5862M and a cost per channel hour of $3225M. Although the total program cost for the HF system is the highest, the cost per channel is lower than the VHF system and only four times the cost of the Ku- or L-band systems. Figure 5 shows a proposed HF-band satellite.

Table 11 presents a cost comparison of the four systems. The HF system has the highest LCC, even at the reduced power level and reduced channel capability. The VHF system has the highest cost per channel hour due to the reduced zones being covered. The VHF spacecraft have the lowest satellite utilization factor.

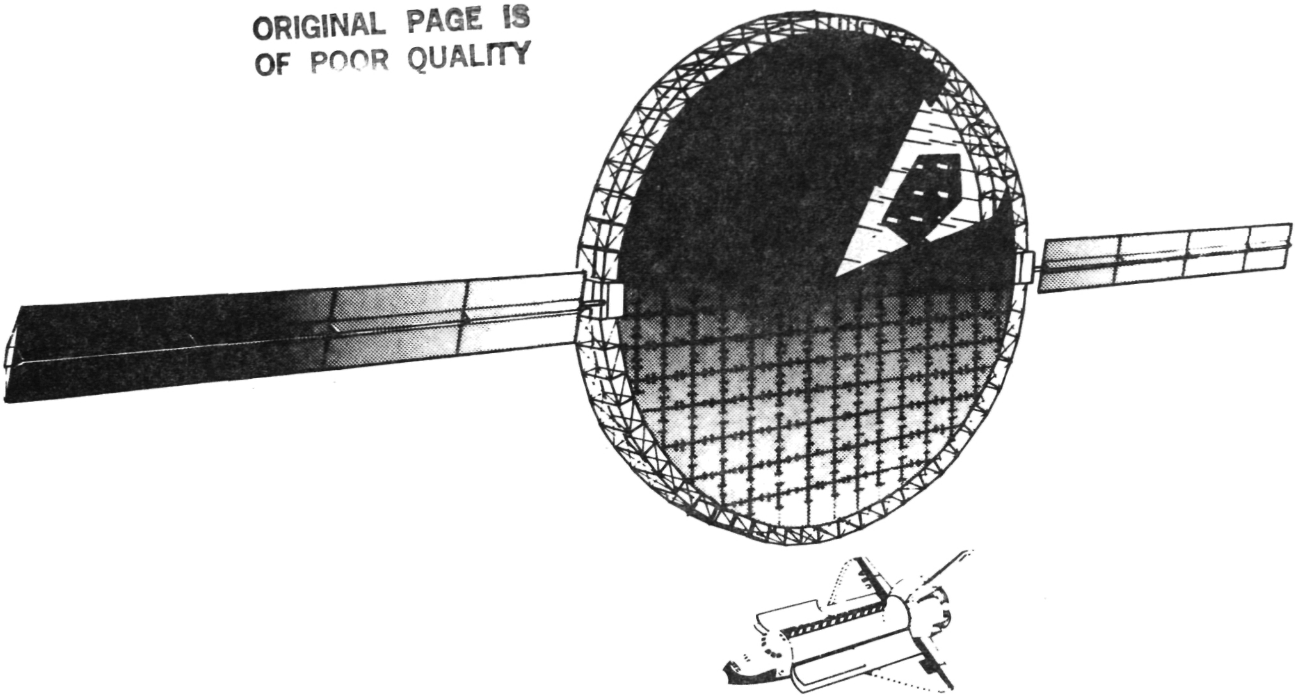

Figure 5. - VHF and HF satellite concepts.

TABLE 10. - SUMMARY OF PROGRAM RESULTS FOR HF SYSTEM

Eight HF-band satellites in an 8-h circular orbit can meet 150 μV/m requirement with reduced channel capability.
- New technology for 80 m array & transmitters
- 93.1 kW satellite power requires space station technology

Zone	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
No. of channels	4	5	1	4	4	4	2	5	6	3	3	4	2	4	2

- LCC = $5,862 m
- Cost/channel hour—$3,225/h
- Centaur G launch vehicle
- 68% coverage frequency

TABLE 11. - COST COMPARISON FOR KU-, L-, VHF-, & HF-BANDS

	No. of spacecraft	LCC	Cost/channel hour
Ku-band	3	$ 1,240M	$ 568/h
L-band (-116.1 dBW/m^2)	3	1,353	619
VHF-band (140 - 150 μV/m)	4	2,945	8,584
HF-band (150 μV/m, reduced channel capability)	8	5,862	3,225
HF-band (300 μV/m, full VOA)	88	52,824	24,181

CONCLUSIONS

The study conclusions are based only on this system study and do not include other significant considerations being evaluated by NASA LeRC and VOA (e.g, receiver population and distribution).

1) Terrestrial systems have the advantage of coverage over nonorbital, nonterrestrial systems because the high power and resulting signal skips for terrestrial systems is more significant in expanding coverage than raising altitude (increasing line of sight) to expand coverage. It is difficult if not impossible to achieve 100-500 kW power levels on either lighter-than-air or heavier-than-air vehicles. The nonorbital, nonterrestrial system does have potential to provide local coverage where existing fixed sights do not exist.

2) Orbital systems can expand coverage for VOA beyond existing terrestrial systems. Orbital systems can be used as an augmentation to the terrestrial system or as a potential replacement. Costs become significant when a full capability orbital replacement system for the HF terrestrial system is considered.

3) Cost of the system increases as the operation frequency decreases.

4) HF is desirable due to high ground receiver population, but antenna size is large and transmit power levels are high. Because of high power requirements at greater than 300 V/m, future tests are desirable to determine if a reduced level (150 V/m) could be received on the ground with adequate S/N ratio.

5) Both HF and VHF systems require technology development for both the power subsystem and the array antenna. The Ku-band system uses OTS technology. The L-band system uses OTS technology except for the array antenna and deployable solar array which are SOA.

6) HF and VHF array antennas have many advantages over reflectors including low power per transmitter, simple thermal control, electronic beam steering, higher reliability (graceful degradation if transmitter fails).

7) Parametric performance studies showed that power generation using deployable photovoltaic solar arrays were superior to other systems based on specific weight (kW/kg) packing volume (kW/stowed volume).

8) Optimizing the HF and VHF VOA coverage requirements for the selected orbit coverage characteristics can improve satellite utilization factors and provide more operational hours and thus reduce cost per channel hour. Also reducing the peak multichannel requirements can improve both the satellite utilization factor and cost per channel hour. Tasking of a satellite to cover more than one zone simultaneously with multiple beams (when satellite power and channel capability is available after covering first zone) can improve both coverage and satellite utilization factors producing lower cost per channel hour.

9) For subsynchronous orbits with multiple satellites, the use of two ground stations with satellite cross linking was more cost effective than additional ground stations and no satellite cross linking.

10) Two smaller HF systems: (1) two satellites in an 8-hour, 0° inclination orbit or (2) two satellites in a triply-synchronous orbit can provide VOA programming with reduced signal strengths but with repeating ground coverage times. This system has significantly lower cost than the full capability system and could be used as a low-cost startup system to augment the terrestrial system.

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